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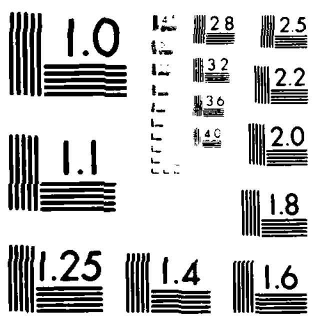
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Report USAFSAM-TR-84-29

A LIMBUS-SENSING EYE MOVEMENT RECORDER

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July 1984

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USAF SCHOOL OF AEROSPACE MEDICINE
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NOTICES

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This report has been reviewed and is approved for publication.

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A limbus-sensing eye movement recorder has been designed to measure horizontal eye position. The recorder uses a modulated infrared light source and a synchronous detector to produce accurate recordings in the presence of ambient light. The recording system bandwidth is dc to 150 Hz, and the signal-to-noise ratio is better than 50 dB. Overall system accuracy is about 0.5^{o} for horizontal eye movement in the $\pm 25^{o}$ range.

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A LIMBUS-SENSING EYE MOVEMENT RECORDER

INTRODUCTION

Accurate recording of eye movements is critical to the study of oculomotor system function. One example is the assessment of smooth pursuit visual tracking where eye movements are studied using frequency domain analysis techniques [1,2]. In early studies eye movements were monitored using ENG recording methods. Eliminating muscle potential artifact and controlling dark adaptation required careful preparation before testing and constant recalibrations during recording sessions. Occasionally subjects had to be retested because of poor quality recordings. To improve the quality of our eye movement data, we investigated the use of alternate eye-movement recording techniques. Young and Sheena [3] have presented an excellent review of eye movement recording methods. Of the seven methods discussed, those based on sensing the iris and sclera boundary (limbus) seemed to offer the best compromise of accuracy, bandwidth, weight, size, and complexity. Subsequently our efforts were directed toward designing a limbus-sensing system with at least 0.5° accuracy for eye movements in the ±25° range, frequency response from dc to over 100 Hz, and good stability.

RECORDING SYSTEM DESIGN

Many authors have described their implementation of limbus-sensing eye movement recorders [4-9]. These recorders utilize the difference in reflectivity between the iris and sclera to determine eye position. The eye is illuminated with an infrared (IR) light source (focused or unfocused, depending on the method), and the reflected IR energy is detected by a pair of photo detectors placed so as to "view" the limbus (Figure 1). As the eye rotates toward one photo detector (and away from the other), the first detector views a greater amount of iris. Since the iris is less reflective than the sclera, the output of this photo detector decreases. Simultaneously, more sclera is viewed by the other photo detector, increasing its output. The difference between the photo detector outputs is amplified and is linearly related to eye rotation over a range of approximately ±25° with horizontal eye movements. If the IR source and photo detectors are accurately placed in a symmetrical manner with reference to the eye, small vertical eye movements will have minimal effect since they will tend not to cause differential changes in the photo detector outputs.

The system described above assumes that the only light detected by the photo detectors is the reflected light from the IR source. To avoid gross errors caused by uncontrolled ambient light (and severe 120-Hz interference from artificial light sources), all testing must either be done in a carefully controlled environment or the system must be designed to reject extraneous light. This rejection can best be achieved by modulating the IR light source at a frequency of several kilohertz and amplifying the photo

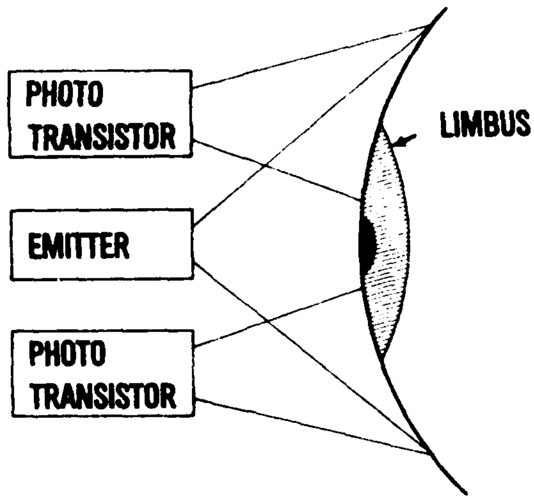

Figure 1. Infrared emitter-detector arrangement.

detector outputs with a tuned amplifier that passes only signals at the modulation frequency and a suitable bandwidth around it. The resulting signal is then demodulated to recover the eye movement information. This not only minimizes problems with ambient light interference but also eliminates a source of drift since the high-gain preamplifier does not have dc response.

Many of the older systems described in the literature use incandescent bulbs and IR filters as light sources, mechanical light-beam modulators, resistive photo cells, and other design features now obsolete. Rather than simply updating one of the existing designs, we elected to combine the best features of all the older systems and implement a new design using state-of-the-art optoelectronics and integrated circuit technology. The design that ultimately evolved (see Figure 2) is similar to that proposed by Brown et al. [9] , but uses an active band-pass filter in the preamplifier rather than a high-pass filter.

One important feature of the new system is the use of a 3-kHz modulated IR light source and a synchronous demodulator to reject artifacts produced by ambient room light. An active 3-kHz band-pass filter is used in the preamplifier stage to reject the 60- and 120-Hz interference and other noise components from both optical and electrical sources. An active 2-pole, 150-Hz low-pass filter smooths the output of the synchronous demodulator. The final amplifier stage provides a convenient push-button reset feature to set the output to zero volts for a reference eye position, and a gain control. Two such circuits were built, one for each eye, using a common IR emitter driver.

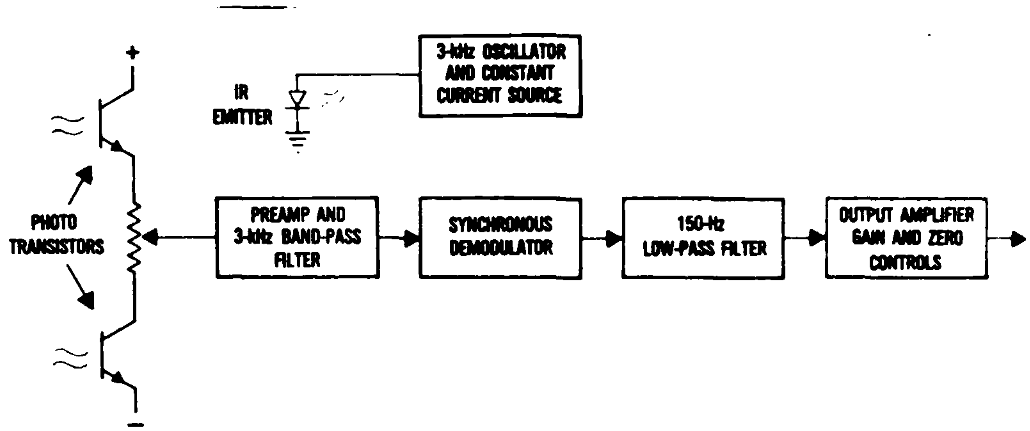

Figure 2. Block diagram of the eye movement recorder.

CIRCUIT

Figures 3 and 4 show the complete circuit for a single-channel eye movement recorder; parts' values are given in Table 1. For a two-channel recorder Q1, Q2, U1, U3, U4, U5, and associated circuit elements must be duplicated and R5 made adjustable. The IR emitter driver shown in Figure 4 can drive either one or two IR emitters (D1 and D2). The analog switch, U2, contains two pairs of switches; the second pair (shown directly above R15 in Figure 3) is available to implement the second recording channel.

We have tried different IR emitters and phototransistors in this circuit and are now using TRW Optron OP-803 phototransistors and OP-132W IR emitters. The linearity of the system is improved by applying a small bias current to the bases of the phototransistors, Q1 and Q2. We do this by placing a large-value resistor (3.3-4.7MΩ) between the collector and base leads of each phototransistor (not shown in the diagram). The most obvious effect of the improved linearity is an increased immunity to artificial light interference, due to a substantial reduction in intermodulation distortion in the phototransistors.

The IR power level obtained from the emitters is proportional to the current flowing through them. This current is provided by the adjustable voltage regulator, U7, which is connected as a constant current source that is switched on and off at a 3-kHz rate by Q3. The current level provided by this source is controlled by the programming resistor R29. The current is given by the equation I(mA)=1200/R(ohms). Thus, R29 of 24 ohms would provide an "on" current of 50 mA; but since the duty cycle of the current source is 50%, the average current through the IR emitters would be about 25 mA. For the OP-132W emitters this would correspond to about 1 mW average power output from each emitter.

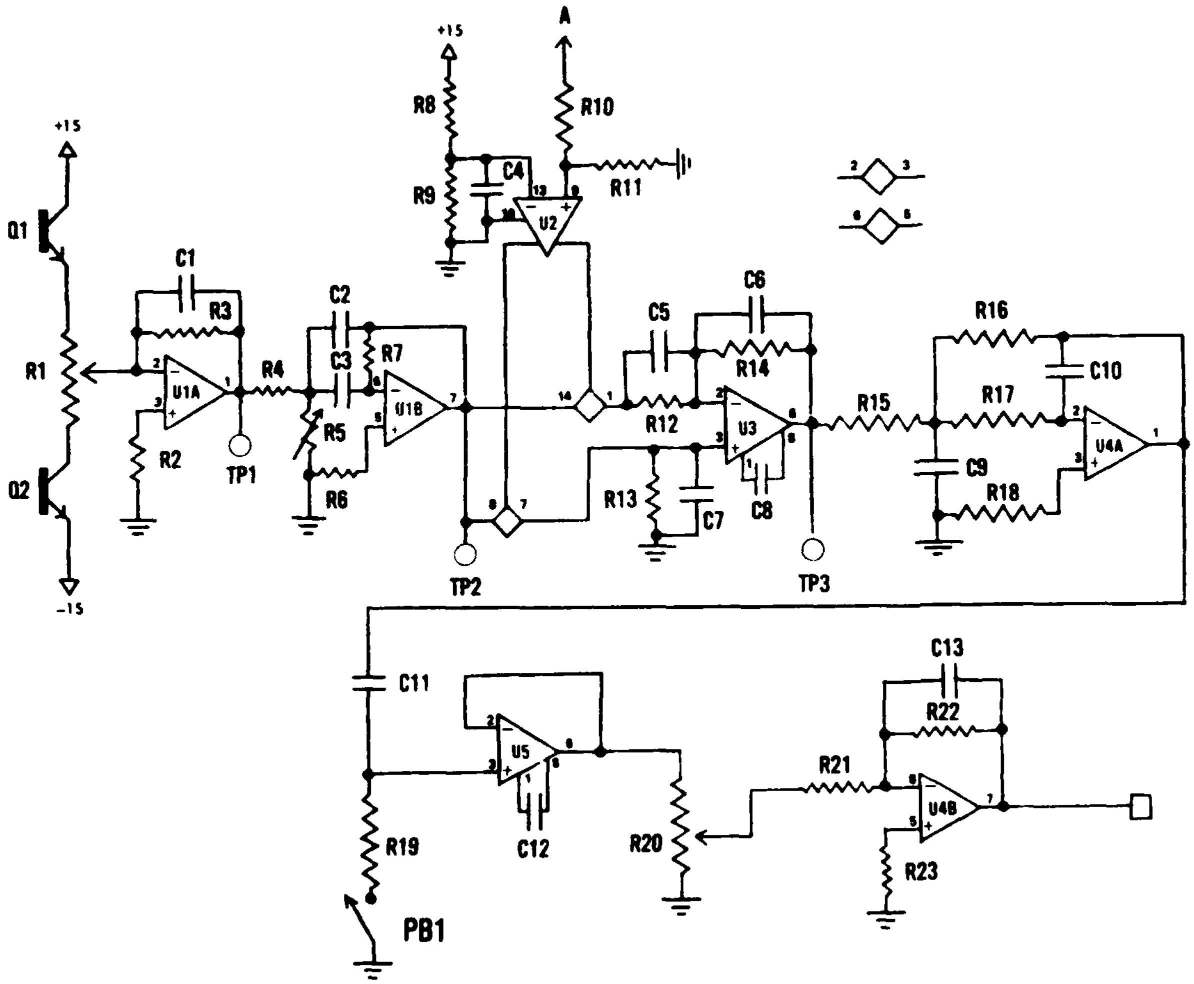

Figure 3. Schematic diagram of the eye movement recorder. (TP1-TP3: tie points; PB1 = push-button one.)

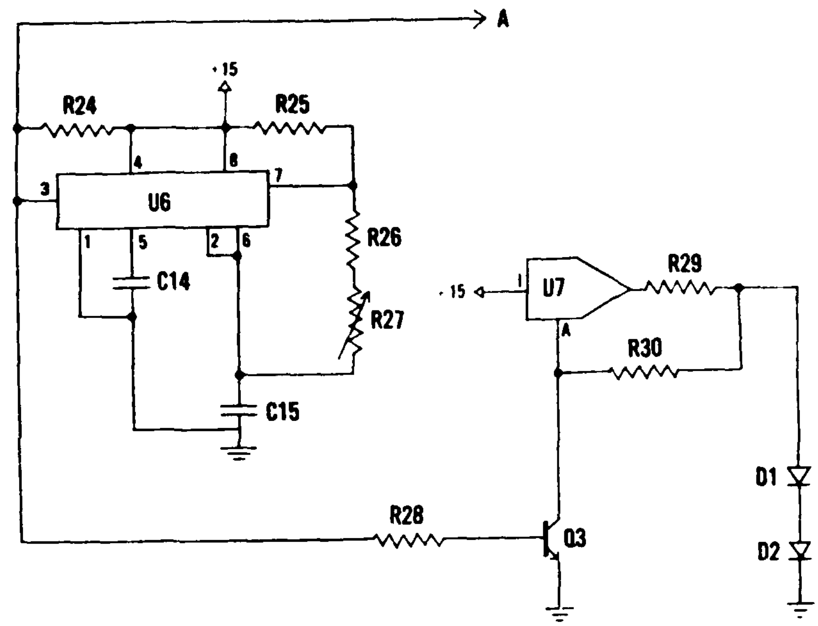

Figure 4. Schematic diagram of the 3-kHz oscillator and IR emitter driver.

TABLE 1. PARTS LISTING

Resistors (Values in ohms; fixed resistors are 0.25 W, 5%)

R1	10K Pot.	R15, 16	22K
R2	12K	R17	27K
R3	100K	R18	39K
R4	15K	R20	5K Pot.
R5	910 fixed or 1K Pot.	R21	47K
R6, 7	330K	R22	100K
R8, 24	4.7K	R23, 26	33K
R9, 19	1K	R25	680
R10	5.6K	R27	25K Pot.
R11, 28	3.3K	R29	See text, p.3
R12, 13, 14	10K	R30	270

Capacitors (Values in microfarads unless otherwise indicated; 5% Mylar except the 30 pF which are ceramic)

C1, 5, 6, 7, 8, 12	30 pF	C9	0.1
		C10	0.02
C2, 3, 13	0.0033	C11	5.5
C4, 14	0.01	C15	0.005

Semiconductors

D1, 2	TRW OP-132W	U3	LM301AN
Q1, 2	TRW OP-803	U4A, B	LM4558N
Q3	2N3904	U5	LM308N
U1A, B	LM4558N	U6	LM555CN
U2	AH0164CD	U7	LM317T

CIRCUIT ADJUSTMENTS

Adjustment of the eye movement recorder is simple. First, R27 (Figure 4) is adjusted to produce a frequency of about 3 kHz at point A. Next, R1 (Figure 3) is adjusted to remove the dc offset at TP1. Then, R27 is readjusted to center the IR-emitter modulation frequency in the passband of the 3-kHz filters. This is accomplished by monitoring TP3 with an oscilloscope (on the channel where R5 is fixed) and adjusting R27 until complete half-cycles are gated through the synchronous detector. Proper adjustment of R27 results in a waveform at TP3 that resembles a full-wave rectified sine wave signal. The second channel (if implemented) is brought into alignment with the first by adjusting R5 to "tune" the 3-kHz filter to produce the proper waveform at TP3 of the second channel.

CALIBRATION

Once the circuit adjustments are made, the recorder is ready for calibration. Using the IR emitters and phototransistors described, we have determined that a 10- to 15-mm space between an eye and emitter-detector is near optimum. This spacing provides good sensitivity and linearity over an eye movement range of ±25°. The proper lateral positioning of the emitter-detector set is determined by starting from a reference position and noting the recorder output for +20° eye movement and then for -20° eye movement. The emitter-detector set is then repositioned slightly and the recorder output tested again until equal magnitude (but opposite polarity) outputs are obtained for ±20° eye movements. Once the mechanical adjustments are complete, the gain control (R20) is adjusted to provide a convenient scale factor for the recorder output.

SYSTEM PERFORMANCE

To evaluate the performance of the eye movement recorder, we constructed a simulated eye-like target. This "eye" consisted of a 25-mm-diameter Teflon cylinder with a 12-mm-diameter black dot attached to represent the iris. The cylinder was mounted on the shaft of a dc torque motor to provide an axis for rotation. A mirror attached to the cylinder reflected a laser beam to a scale located several meters away, allowing the precise angular position of the cylinder to be determined. This test setup was used to determine the best emitter-detector--eye geometry and to establish the static accuracy of the recorder. A 15-mm center-to-center space was maintained between the two phototransistors (detectors) for all testing; the IR emitter was centrally located between the detectors, as illustrated in Figure 1. The results of the static testing are given in Table 2. The dynamic performance was evaluated by driving the dc torque motor to rotate the simulated eye at various angular velocities. The recorder output was then monitored with an oscilloscope. The response of the system was consistent with the design bandwidth of 150 Hz.

TABLE 2. STATIC-TEST DATA

10-mm space between emitter-detector and eye:

Regression equation: $Y=9.9952X-0.1090$
$r=0.9993$

Maximum deviation from best straight-line fit over a ±25° range: 0.13°

Signal-to-noise ratio: 55 dB

15-mm space between emitter-detector and eye:

Regression equation: $Y=10.076X+0.3334$
$r=0.9997$

Maximum deviation from best straight-line fit over a ±25° range: 0.36°

Signal-to-noise ratio: 55 dB

DISCUSSION

The static performance outlined in Table 2 represents the upper limit of performance that can be expected. In actual use, where the position of the emitter-detector assembly is not absolutely fixed with reference to the eye and the reflectivity of the eye is not perfectly uniform, we would expect somewhat poorer performance. Careful alignment of the device with a human subject fixating on stationary targets should provide an accuracy better than ±1° in practice. The resolution of the recorder is determined by the signal-to-noise ratio and is about 0.07°. Improving the resolution requires an increase in the signal-to-noise ratio; this can be achieved by increasing the illumination level of the IR emitter or reducing the system bandwidth, or both.

REFERENCES

1. Wolfe, J.W., E.J. Engelken, J.E. Olson, and J.P. Allen. Cross-power spectral density analysis of pursuit tracking: Evaluation of central and peripheral pathology. Ann Otol Rhinol Laryngol 87:837-844, 1978.

2. Engelken, E.J., and J.W. Wolfe. A modeling approach to the assessment of smooth pursuit eye movement. Aviat Space Environ Med 50: 1102-1107, 1979.

3. Young, L.R., and D. Sheena. Survey of eye recording methods. Behav Res Meth Inst 7(5):397-429, 1975.

4. Torok, N., V. Guillemin, Jr., and J.M. Barnothy. Photoelectric nystagmography. Ann Otol Rhinol Laryngol 60:917-926, 1951.

5. Stark, L., G. Vossius, and L.R. Young. Predictive control of eye tracking movements. IRE Trans Human Factors Eng HFE-3:52-57, 1962.

6. Wheeless, L.L., R.M. Boynton, and G.H. Cohen. Eye movement responses to step and step-pulse stimuli. J Opt Soc Am 56(7):956-960, 1966.

7. Findlay, J.M. A simple apparatus for recording microsaccades during visual fixation. Q J Exp Physiol 26:167-170, 1974.

8. Gauthier, G.M. and M. Volle. Two-dimensional eye movement monitor for clinical and laboratory recordings. Electroencephalogr Clin Neurophysiol 39:285-291, 1975.

9. Brown, B., A.J. Adams, A. Jampolsky, and M. Muegge. A clinically useful eye movement recording system. Am J Optom Physiol Opt 54(1):56-60, 1977.

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